

# An investigation of linearity and sensitivity of Fiber Bragg Grating sensors

B. A. TAHIR\*, J. ALI, R. A. RAHMAN, A. AHMED<sup>a</sup>

*The Institute of Advanced Photonic Sciences, Faculty of Science, University of Technology Malaysia, 81310 Skudai, Johor, Malaysia*

<sup>a</sup>*Center of Excellence in Solid State Physics, University of Punjab Lahore, Pakistan*

In this work, we investigate the linearity and sensitivity of Fiber Bragg Grating (FBG) sensors. A simple experimental setup comprising optical spectrum analyzer, tunable laser source and fiber grating may be utilized to obtain the wavelength shift and strain measurements. The sensing principle is based on tracking of Bragg wavelength shifts due to the change of loading conditions. The experiment was performed on a fiber grating bonded specimen plate made of Zinc. From the experiment, measure the wavelength shift and then axial strain corresponding to the variation of applied load/temperature change. Based on the results, a linear response has been observed between applied strain/temperature and Bragg wavelength shift throughout the measured region. It has also been demonstrated that the fiber Bragg grating system is more sensitive for 10cm sensor. The measured sensitivity of 10cm and 15cm sensor is 0.0011nm/ $\mu$ m and 0.0016nm/ $\mu$ m respectively at the same loading conditions. One can also anticipate 0.014nm grating wavelength expansion as a result of temperature change of 1°C to bare FBG fiber. The experimental results are also showing the capability of the proposed system to perform strain/temperature measurements.

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## 1. Introduction

Fiber Bragg grating has the important property of performing as linear relationship with the measurands. They strongly reflect light from an incident broadband source over a narrow wavelength range and transmit without changing all other wavelengths, producing a dip in the transmitted spectrum at the same wavelength range [1]. Fiber Bragg gratings (FBG) are widely used as wavelength-selective dielectric mirrors in the core of an optical fiber. These gratings consist of a periodic refractive index pattern in the fiber core. The function of such a grating can be understood as the coherent interaction of the Fresnel reflections caused by every single refractive index step. The index modulation is typically achieved by the photosensitivity of doped fused silica under illumination by UV laser light or by exposure with high-intensity IR femtosecond laser pulses [2]. Fiber Bragg gratings have found manifold applications in optical telecommunication, laser and sensor technology. They have a great variety of uses, e.g., as filter elements, laser mirrors or strain and temperature sensing elements [3]. FBGs have been employed in a variety of engineering applications involving internal strain measurements in composite plates, monitoring and control of structures in service, damage detection and non-destructive testing. This is essentially due to their ability to perform direct strain measurements inside/outside host structures at desired locations thus, providing valuable information of the local strain state in complex structures [4].

FBG sensors have been established as a major leading technology as compared to other competing fibre optic sensor technologies. The main advantages of FBGs over other fibre sensor schemes are its low cost, good linearity, wavelength multiplexing capacity, resistance to harsh environments and the transduction mechanism, which eliminates the need for referencing as in interferometric sensors. FBG sensor technology is now on the verge of maturity after almost two decades of active research and development in this field. Efforts are now concentrating on delivering complete FBG sensor systems including front-end electronics. This paper aims to provide investigations for writing fiber Bragg gratings of extending conventional techniques to the visible spectrum range and in particularly, discuss the linearity of wavelength shift as a function of temperature change/axial strain, and sensitivity of fiber Bragg grating system.

## 2. Materials and Methodology

In general, the FBG system is comprised of broadband source, coupler, optical spectrum analyzer and optical fiber with prewritten grating sensors. When a section of fiber containing a grating is subjected to axial strain, the grating spacing and refractive index has been changed. Both affect the Bragg wavelength. In this fashion, the grating acts as a sensor to detect strain [5]. The schematic experimental arrangements to measure the wavelength shift for 10cm sensor and 15 cm is shown in Figure 1. The experiment was performed on a specimen made of zinc

having dimension 400 x 100 x 2mm (l x w x t). The fiber Bragg grating sensor was a piece of 1000mm bare optical fibre with 120mm stripped section in the middle, in which 30mm was written with Bragg gratings by phase mask technique. The stripped section was not recoated after FBG inscription. FBG was bonded onto the material i.e. zinc plate. The pressure gauge comprised of the turning screw which was supported by a steel plate at the bottom. The light from tuneable laser source was launched into the

optical spectrum analyzer through fiber Bragg grating. The turning screw was turned to apply the load, followed by pushing the single sweep button from OSA. The elongation in the grating was produced by turning the screw gauge. The wavelength shift in the spectrum was monitored against each gradually increasing value of load on the screen of OSA. All the experimental procedure for 15cm sensor is same as for 10cm sensor, except the sensor length i.e. 15cm.

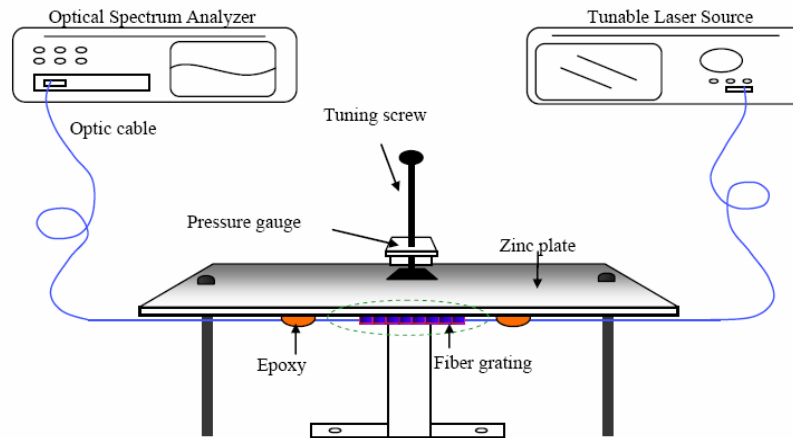


Fig. 1. A schematic of experiment setup for 10cm and 15cm sensor

For the strain monitoring, load was directly transferred from host material to fibre core of the grating region by the action of strain. This caused the length of the grating region to be changed and the resultant refractive index of the core section to vary accordingly. The mechanical properties of the structure are simply determined by measuring the reflected wavelength change from the system. The strain response arises due to both the physical elongation of the sensor (and corresponding fractional change in grating pitch) and the change in the refractive index due to photoelastic effects. These include monitoring of wavelength shift from optical spectrum analyzer and close observation of applied load through screw gauge on the FBG bonded zinc plate. In principle, the reflection spectrum of a FBG is complementary to its transmission spectrum, although this is not realized in practice because of transmission losses, which may result from the conversion of coupling modes to cladding modes [6].

### 3. Results and discussions

The corresponding transmission spectra for 10cm and 15cm sensor are obtained from optical spectrum analyzer after the FBG was strained with the load application by turning the screw gauge on the zinc plate. The Bragg wavelength  $\lambda_B$  and Bragg wavelength shift  $\Delta\lambda_B$ , were obtained from optical spectrum analyzer. The operating principle is that the grating reflects different wavelength component of the signal for different section along the

grating. It is also clear from the transmission display that the values of Bragg wavelength and hence the Bragg wavelength shift are gradually increased by enhancing the applied load. If the applied load is uniform, then the Bragg wavelength shifts occur without modification of the initial spectrum shape. The axial strain for the experimental setup was calculated against each value of Bragg wavelength shift. The strain effect term could be expressed by equation as below and it points out that the shift in wavelength of the Bragg peak is proportional to the applied axial strain. The equations (1) and (2) show the linear relationship between wavelength shift ( $\Delta\lambda_B$ ) and measurand i.e. temperature and applied strain.

$$\Delta T = \Delta\lambda_B / (\xi + \alpha) \lambda_B \quad (1)$$

$$\varepsilon = \Delta\lambda_B / (1 - p_e) \lambda_B \quad (2)$$

#### 3.1 Linearity of Fibre Bragg Grating Sensor

Fiber grating has the linear relationship with the measurand. From the results and calculations obtained from 10cm & 15cm sensor experiment, it is clear that the measured strain/temperature change and wavelength shift have larger values for smaller sensor length i.e. 10cm and vice versa. The linear relationship of wavelength as a function of temperature change is shown in Figure 2. Figure 2, shows the effect of temperature change for a

fiber grating 1551.374 nm. The results under variable temperature from 30°C to 190°C at constant strain have a shift from 0.328nm to 2.528nm in the Bragg grating wavelength as a function of applied temperature. The dependence of the Bragg wavelength on temperature arises due to two primary effects: the dependence of the index of refraction of the glass on temperature and the thermal expansion of the glass. In silica fibers, the former of these is the dominant effect, accounting for  $\sim 95\%$  of the

observed shift. The comparison plot for 10cm & 15cm sensor between axial strain and wavelength shift can also be drawn and is shown in Figure 3. Figure 3 shows the linearity of the fiber Bragg grating system. There is a good correlation between applied strain and Bragg wavelength shift obtained from two experimental setups. A linear response has been observed between applied strain/temperature change and Bragg wavelength shift throughout the measured region.

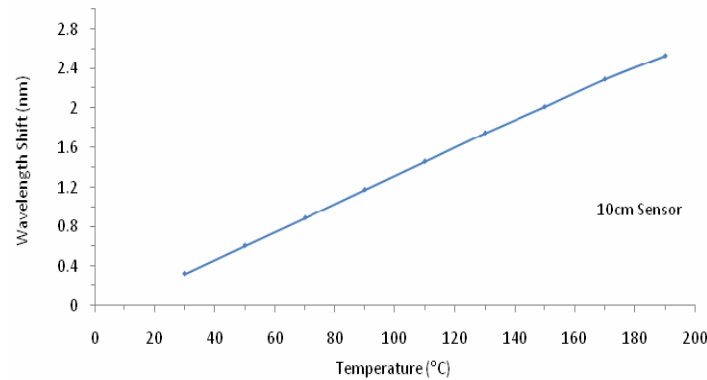


Fig. 2. Wavelength shift versus Temperature change for 10cm sensor (Linearity)

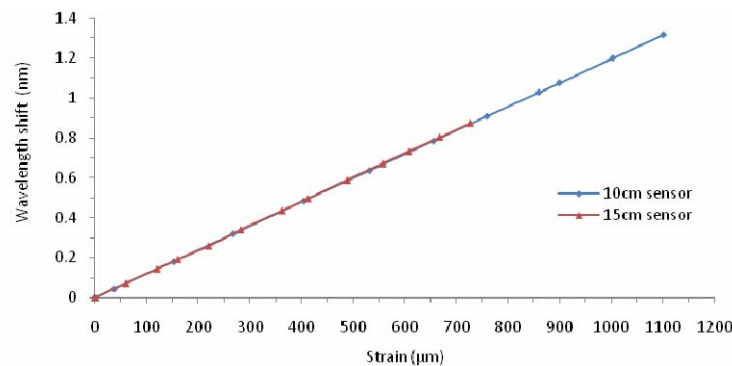


Fig. 3. Wavelength shift versus applied strain for 10cm & 15cm sensor (Linearity)

### 3.2 Sensitivity of Fibre Bragg Grating Sensor

According to the results, it is reported that the Bragg wavelength shift and axial strain are varied with sensor length under the same loading and temperature. If the sensor gauge length is smaller, then the shift in the Bragg wavelength and applied strain are larger and vice versa. It means that the fiber Bragg grating system is more sensitive for smaller sensor length i.e. 10 cm and less sensitive for larger sensor length i.e. 15 cm. The measured

sensitivity of 10cm and 15cm sensor is 0.0011nm/μm and 0.0016nm/μm respectively at the same value of applied strain. In Figure 4, the longer columns are showing the larger values of Bragg wavelength shift or, in other words, more sensitivity of the fiber Bragg grating system and shorter columns are showing the smaller values of Bragg wavelength shift or, in other words, less sensitivity of the fiber Bragg grating system. The graph below shows the sensitivity of the fiber Bragg grating system

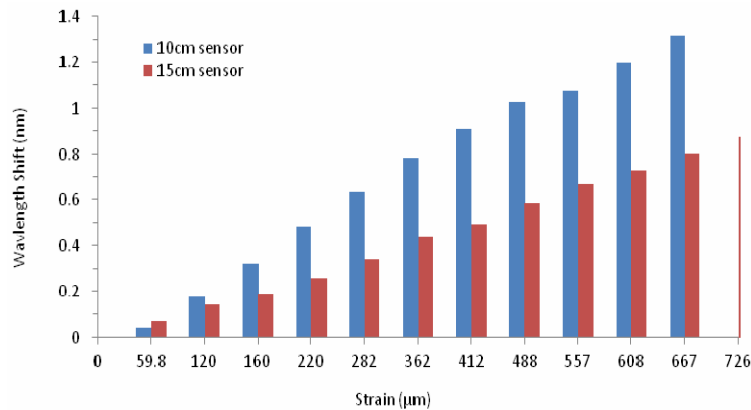


Fig. 4. Wavelength shift versus applied strain for 10cm & 15cm sensor (Sensitivity)

In this work, a simple fiber Bragg grating sensing system to observe the effect of sensor length on the axial strain, linearity and sensitivity in terms of Bragg wavelength shift has been discussed. Results of transmission spectrum and reflectivity of light in fiber Bragg grating system have been found to have a relationship with Bragg wavelength when monitoring the strain effect on an optical fiber Bragg grating. This is corresponding to change in the grating spacing and the refractive index of a fiber [7]. Therefore, it is shifted in the Bragg's wavelength. Besides, the linear characteristic of the graph between wavelength shifts versus strain shows us that the wavelength shifting is proportional to the different of the strain. However, this linearity has a threshold level where at this point the FBG will break. This experiment was only done below the threshold point to avoid this effect. The good linear relationship between longitudinal strain and Bragg wavelength shows the potential of using device (FBG) sensing applications for water tanks, metallic and steel structure monitoring.

#### 4. Conclusion

The FBG sensor showed accurate and precise results in strain experiments. Due to the photoelastic nature, FBG sensors grating wavelength shift is regressively linear along with its axial strain. Considering the bare FBG fibers used in the experiment, one can anticipate approximately 1.2 pm grating wavelength increase increases as a result of axially applying 1με strain to bare FBG fiber. One can also anticipate 0.014nm grating wavelength expansion as a result of temperature change of 1°C to bare FBG fiber. From the results, it is concluded that the fiber Bragg grating system is more sensitive for 10cm sensor and measured sensitivity of 10cm and 15cm sensor is 0.0011nm/μm and 0.0016nm/μm respectively at the same applied strain. It is inferred from the co-relation of longitudinal strain verses Bragg wavelength shift, that it can be used as an applications in optical sensing as high temperature sensor, fire alarm sensor, vibration sensor, and pressure sensor.

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#### References

- [1] R. M. Measures, Structural monitoring with fibre optic technology, Meas Sci Technol., **12**, 1609 (2001).
- [2] S. J. Mihailov, C.W. Smelser, P. Lu, R. B. Walker, D. Grobnc, H. Ding, G. Henderson, J. Unruh, Opt. Lett. **28**, 995 (2003).
- [3] E. Wikszak, J. Thomas, J. Burghoff, B. Ortac, J. Limpert, S. Nolte, U. Fuchs, A. Tünnermann, Opt. Lett. **31**, 2390 (2006).
- [4] A. Othonos, K. Kalli, FBG: Fundamental and applications in Telecommunication and sensing (Artech House, Boston, 1999)
- [5] B. A. Tahir, J. Ali, R. A. Rahman, Am. J. Applied Sci., **special issue**, 40 (2005).
- [6] K. Fukuchi et al., Hitachi Cable Rev., **21**, 23 (2002).
- [7] C. Li, Y. M. Zhang, Y. G. Zhao, L. J. Li, Fiber Grating: Principles, Techniques and Applications, (Science Press, Beijing, 2005).

\*Corresponding author: drbashirtahir@gamil.com